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Vendor Managed Inventory Systems with Emission Related Costs

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The role of logistics and supply chain has come into prominence in helping the firms achieve their economic and sustainability objectives. Specifically, realignment of business processes, as characterized by supply chain coordination, has the potential to have a significant impact in this regard. In our study, we consider a supply chain with a single vendor and multiple retailers. Initially, we assume that the retailers take care of their respective replenishment decisions. Then, we show that by adopting vendor managed inventory, the organizations involved can benefit through cost reduction, and at the same time reduce their greenhouse gas emissions, thereby highlighting the role of supply chain coordination in meeting the twin objectives. We provide managerial and policy insights based on our numerical analysis.

Keywords: *Vendor managed inventory, greenhouse gas emission, supply chain coordination*

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1. Introduction

Policy makers have instituted wide ranging measures to combat environmental deterioration and stakeholders across the spectrum have been trying to analyze this issue from a variety of perspectives and across geographies. The shift to the triple bottom line reporting, with its focus on people, planet and profits is symptomatic of this changed thinking. Governments across the world have also been trying to institute policies and guidelines that facilitate the adoption of environmentally friendly practice and processes in organizations. For example, the European Union Emissions Trading Scheme (EU ETS) is one of the largest such initiatives covering several thousand factories and other installations. Under this scheme, which operates on the cap and trade system, the total amount of greenhouse gas (GHG) emissions are capped for the participating facilities and the allowances for these emission are allocated or auctioned. Breach in these limits result in penalties. Programs with similar objectives and different stipulations have been instituted in other countries also.

Driven in part by the impetus provided by such mechanisms, organizations have been striving to modernize their ways of planning and operations (Toptal et al., 2013). At the same time, companies would be more willing to implement 'green' practices if they can gain both financial and environmental benefits (Bowen et al., 2001). These practices have been incorporated across various areas, including supply chains (SC), thereby giving rise to new way of functioning (Al-e-hashem and Rekik, 2013).

In our paper, we present one such approach in which we show that SC coordination through vendor managed inventory (VMI) can lead to significant economic benefits, and at the same time lead to a reduction in GHG emission.Our work builds on existing studies that try to integrate the production, inventory and transportation decisions along with a focus on the environmental considerations as well. We compare and contrast the results obtained under two modes of operations, viz. retailer managed replenishment and VMI.

Recent literature surveys of the broader field of green supply chain management are available (see for example Sarkis et al., 2011). In our paper, we focus on a more focused domain of integrating environmental considerations in operational decision making. Specifically, we integrate the literature on VMI and emission related lot sizing models. According to Hines et al. (2000), VMI is a collaborative strategy between a retailer and a vendor to optimize the availability of products at minimal cost to the two companies. The responsibility of managing the replenishment decisions rests with the vendor who in turn gains access to actual demand information. Benefits of VMI adoption that can be found in literature include a reduction in costs for the parties involved, reduction in inventory requirements, as well as a decrease in the bullwhip effect (Sari, 2008). However, due to operational control, the supplier may be tempted to place extra inventory at the retailer's facility. In order to counter this opportunistic behavior, a slightly modified form VMI called VMI with consignment has been suggested.

Under the latter, the supplier bears the financial component of the holding cost for the stock kept downstream (Ben-Daya et al., 2013) This increased investment acts as a check against improper vendor behavior. Several aspects of VMI systems have been investigated by researchers. For detailed reviews, readers are referred to Marques et al. (2010) and Govindan (2013).

The issue of GHG emissions with respect to the lot sizing decision has not received much attention (Absi et al., 2013). Benjaafar et al. (2013) developed some simple models that illustrated how carbon emission considerations could be incorporated in operational decision making. Bonney and Jaber (2011) presented an EOQ model with environmental considerations which accounted for transportation cost and GHG emission related taxes. Several researchers then built on their work by incorporating a variety of assumptions (Hua et al., 2011; Wahab et al., 2011; Bouchery et al., 2012).

Jaber et al. (2013) investigated a two level SC with one vendor and one buyer with emission related costs. Extending their work, Zanoni et al. (2013) showed that VMI systems with consignment stock can be used to reduce the total system costs. Both these papers considered systems with two GHG related costs, viz. an emission related tax which is levied on per unit of GHG emission and a penalty in case total GHG emission breach a prescribed upper limit.

Our paper builds on this stream of literature in several ways. First, we take a more complex system with a vendor and multiple retailers and analyze both the cost and environmental benefits associated with adoption of VMI. This approach can purportedly lower GHG emissions more effectively and more efficiently than the adoption of green technologies (Benjaafar et al., 2013). Second, we also consider the impact of transportation costs which are often neglected in literature even though they are a significant part of operating costs (Govindan, 2013). Third, we derive managerial and policy implications from our work that would be helpful from a practical viewpoint. In essence, we accentuate the evidence for the argument that it is indeed possible for business practices to make economic as well as environmental sense, provided that the underlying mechanisms are critically and comprehensively explored.

The problem has been explained in the next section. Mathematical models for the two modes of operation have been presented in sections 3 and 4 respectively. Numerical analysis has been carried out in section 5. In section 6, we discuss the managerial and policy insights from our analysis. Concluding remarks have been provided in the last section.

2. Problem statement

We consider a system with a single vendor who manufactures and supplies a single product to multiple retailers. Initially all the retailers are responsible for their respective replenishment decisions. In the second case, it is assumed that the parties enter into a VMI agreement with consignment, i.e. the vendor takes on the responsibility of replenishing the retailers. At the same time, the financial component of the holding cost incurred for the stock kept at various retailer locations is borne by the vendor. Thus, the retailers incur only the physical component of the holding cost and the transportation cost.

Other assumptions involved in our study and the notations used are given below.

Assumptions:

(1) Demand rate is deterministic and is assumed to be constant over time.
(2) The production rate of the vendor is finite but is bound by upper and lower levels.
(3) The deliveries are synchronized such that there are no backorders.

Notations:

D_i	Demand rate for the i^{th} retailer (units/year)
D	Total demand rate across all the retailers (units/year)
r	Number of retailers in the system
P	Production rate of the vendor (units/year)
P_{min}	Minimum production rate (units/year)
P_{max}	Maximum production rate (units/year)
n	Number of delivery sub-batches in a production batch
A_v	Vendor's setup cost ($/setup)
A_i	Ordering cost for the i^{th} retailer ($/order)
t_i	Transportation cost for the i^{th} retailer ($/order)
T	Length of the replenishment cycle (years)
h_v	Vendor's holding cost ($/unit/year)
h_{vp}	Physical storage component of vendor's holding cost ($/unit/year)
h_{vf}	Financial component of vendor's holding cost ($/unit/year)
h_i	Holding cost of the i^{th} retailer ($/unit/year)
h_{ip}	Physical storage component of retailer's holding cost ($/unit/year)
h_{if}	Financial component of retailer's holding cost ($/unit/year)
a	Emission function's factor (tonne year^2/unit^3)
b	Emission function's factor (tonne year/unit^2)
c	Emission function's factor (tonne/unit)
C_t	Emissions tax ($/tonne)
C_p	Emission penalty for exceeding emission limit ($/year)
E	GHG emissions (tonne/unit)
Y	Binary emissions limit variable (Y is1 if the emission limit is exceeded, otherwise 0)
TC_i	Total cost incurred by the i^{th} retailer ($/year)
TC_v	Total cost incurred by the vendor ($/year)
TCE	Total cost related to the GHG emissions ($/year)
TSC	Total cost of the system ($/year)

3. Independent ordering by the retailers

When the retailers act independently, it is optimal for them to operate according to their economic order quantity. Correspondingly, the optimal replenishment cycle for the i^{th} retailer can be written as:

$$T_i = \sqrt{\frac{2(A_i + t_i)}{h_i D_i}} \tag{1}$$

Total cost incurred by the i[th] retailer, $TC_i = \sqrt{2(A_i + t_i) h_i D_i}$ (2)

The vendor receives orders from the retailers as per their respective optimal replenishment cycles. In this scenario, it becomes difficult to determine vendor's cost. However, following Chan and Kingsman (2007), we assume that the vendor caters to a constant demand rate, which is equal to the total demand rate across all the retailers ($D = \sum_{i=1}^{r} D_i$). At the same time, he carries extra stock equal to the sum of the economic order quantities of the retailers, in order to avoid stockouts.

Thus, the vendor manufactures the product as per his economic production quantity at a time interval T_v given by:

$$T_v = \sqrt{\frac{2A_v}{h_v D\left(1 - \frac{D}{P}\right)}} \tag{3}$$

The vendor's total annual operating cost can be written as the sum of total setup cost and total holding cost (including the safety stock):

$$TC_v = \frac{A}{T_v} + h_v \left[\left\{ \frac{DT_v}{2}\left(1 - \frac{D}{P}\right) \right\} + \left\{ \sum_{i=1}^{r} D_i T_i \right\} \right] \tag{4}$$

Next, we account for GHG emissions for the system. Bogashewsky (1995) provided the relationship between the production rate of a process and the rate of GHG (CO_2) emission as:

$$E = aP^2 - bP + c \tag{5}$$

Such convex functions of the production rate or equipment speed have been empirically validated for car engines (TÜV Rheinland, 1987). Moreover, similar relationships have been established for other production processes also (Fandel, 1991; Jaber et al., 2013)

Similar to the US emission carbon tax system, we assume that a cost is incurred per tonne of GHG emission. Furthermore, similar to the EU-ETS system, we also assume that a penalty is levied in case the total emissions exceed a prescribed upper limit. Then, the total emission related cost can be written as:

$$TCE = E * D * C_t + Y * C_p \tag{6}$$

The first term gives the total emission tax (charged on per unit of GHG emission) and the second term corresponds to the penalty levied in case the limit is exceeded and the binary variable Y will take the value 1 in this case. Thus, the total system cost under retailer managed replenishment can be written as:

$$TSC = \sum_{i=1}^{r} TC_i + TC_v + TCE \tag{7}$$

The decision variable for the retailer, viz. the length of the replenishment cycle as well as the total cost incurred can be determined from equations (1) and (2). The decision variable for the vendor, viz., T_v and P can be determined by optimizing the sum of total vendor operating cost from equation (4) and the total emission related cost from equations (5) and (6).The optimization problem can be written as:

$$\begin{aligned}
&Min \;\; TC_v + TCE \\
&\text{s.t. } \; TC_v = \frac{A}{T_v} + h_v \left[\left\{ \frac{DT_v}{2}\left(1 - \frac{D}{P}\right) \right\} + \left\{ \sum_{i=1}^{r} D_i T_i \right\} \right] \\
&TCE = E * D * C_t + Y * C_p \\
&E = aP^2 - bP + c \\
&E - E_{\lim} \le Y * M \\
&P_{\min} \le P \le P_{\max} \\
&P, T_v \ge 0 \\
&Y \in \{0,1\}, M \text{ is a very large number}
\end{aligned} \tag{8}$$

Note that M is a very large number, which will help in ensuring that the binary variable Y takes a value of 0 whenever the value of E remains below the specified limit. The values of T_i can be calculated as explained previously and subsequently used here. This optimization problem can be solved using any mathematical software.

4. VMI model

Most of the papers in this domain consider VMI systems with equal batch sized deliveries to the retailers (see for example, Zanoni et al., 2011 and Yu et al., 2012). However, Chatterjee and Ravi (1991) showed that a for a system with a single manufacturer and a single retailer, it may be more beneficial if the deliveries took place in such a way that the size of each delivery sub-batch is more than the previous batch by a factor P/D. We take a similar approach for our multi-party VMI system. In our model, the vendor makes *n* deliveries to the retailers in a given production setup. However, the size of the delivery batch increases each time by a factor *x* (=P/D). Thus, in this case, the delivery to retailers takes place in ‘n’ batches of increasing size (Figure 1).

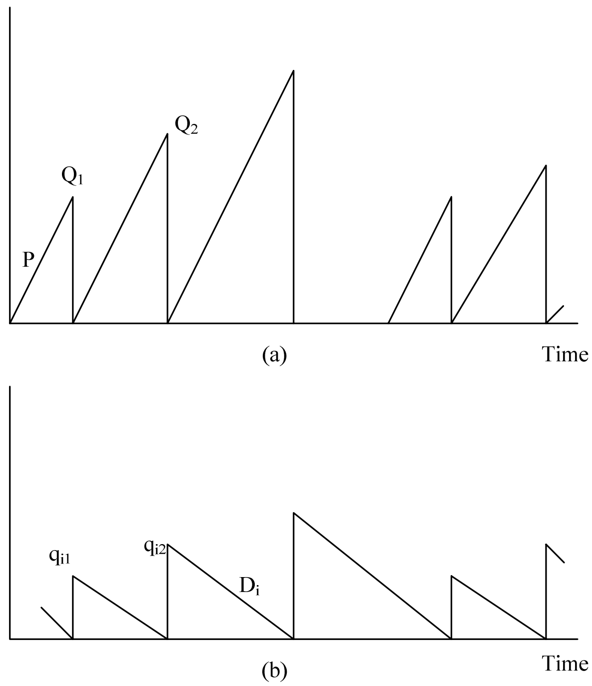

Figure 1. Inventory profile under VMI for (a) vendor, and (b) ith retailer

From the figure, the total vendor cost can be written as

$$TC_v = \frac{A + n\sum_{i=1}^{r} a_i}{T} + \frac{h_v T D^2}{2P}\left[\frac{x^{2n}-1}{x^2-1}\right]\left[\frac{x-1}{x^n-1}\right]^2 \tag{9}$$

We must also consider the transportation cost incurred by the system. Under VMI, a significant reduction in transportation cost is possible (Disney et al., 2003). Routing and scale benefits often play an important part. Thus, in order to account for these savings, we consider a transportation efficiency factor β, with a value lying between 0 and 1. It captures the extent of reduction in transportation cost under VMI. A lower value of β would imply higher savings.

Thus, the total transportation costs will be

$$= \frac{n\beta\sum_{i=1}^{r} t_i}{T}$$

Then, using the above expression and from the figure, the total cost incurred by all the retailers will be:

$$\sum_{i=1}^{r} TC_i = \frac{n\beta\sum_{i=1}^{r} t_i}{T} + \frac{T}{2}\left[\frac{x^{2n}-1}{x^2-1}\right]\left[\frac{x-1}{x^n-1}\right]^2 \sum_{i=1}^{r} h_{ip} D_i \tag{10}$$

As in the previous case, the total emission costs can be written as:

$$TCE = E * D * C_t + Y * C_p$$

Thus, the total cost of the VMI system will be:

$$TSC = \sum_{i=1}^{r} TC_i + TC_v + TCE \tag{11}$$

The decision variables in this model are P, T and n. The solution can be obtained by solving the following optimization problem:

$$Min\ TSC = \sum_{i=1}^{r} TC_i + TC_v + TCE$$

$$\text{s.t.} \quad \sum_{i=1}^{r} TC_i = \frac{n\beta\sum_{i=1}^{r} t_i}{T} + \frac{T}{2}\left[\frac{x^{2n}-1}{x^2-1}\right]\left[\frac{x-1}{x^n-1}\right]^2 \sum_{i=1}^{r} h_{ip} D_i$$

$$TC_v = \frac{A + n\sum_{i=1}^{r} a_i}{T} + \frac{h_v T D^2}{2P}\left[\frac{x^{2n}-1}{x^2-1}\right]\left[\frac{x-1}{x^n-1}\right]^2$$

$$TCE = E * D * C_t + Y * C_p$$

$$E = aP^2 - bP + c$$

$$E - E_{\lim} \le Y * M$$

$$P_{\min} \le P \le P_{\max}$$

$$P, T_v \ge 0$$

$$Y \in \{0,1\}, M \text{ is a very large number} \tag{12}$$

5. Numerical analysis

We consider a numerical example to analyze the performance of the two models developed in this paper. The numerical example has been adapted from Jaber et al. (2013) who considered a joint economic lot size model in the presence of emission reduction incentives in case of a SC with a single vendor and a single retailer. However, in our multi-party case we assume a system with a vendor and three retailers. The data used is given in Table 1.

Table 1: Data for the numerical analysis

For the vendor:					
A_v=1000	h_v=60	h_{vp}=55	h_{vf}=5		
P_{up}=3000	P_{lo}=1200	β=0.85			
For the retailers:					
D_1=150	A_1=80	t_1=250	h_1=90	h_{1p}=80	h_{1f}=10
D_2=350	A_2=100	t_2=150	h_2=90	h_{2p}=80	h_{2f}=10
D_3=500	A_3=80	t_3=300	h_3=90	h_{3p}=80	h_{3f}=10
Emission related data:					
a=0.0000007	b=0.0012	c=1.4			
C_t=18	C_p=4000	E_{lim}=220			

We used LINGO 13 to determine the optimal values of the decision variables. Results obtained are shown in the table below.

Table 2: Results obtained for the numerical example

(a) Independent ordering by the retailers					
T_1=0.2211	T_2=0.1260	T_3=0.1300	TC_1=2985	TC_2=3969	TC_3=5848
P=1745	T_v=0.2794	TC_v=15678	TE=3951	E=219.5	TSC=32430
(b) VMI					
T=0.2913	n=2	P=1997	E=200	TE=3600	
TC_1=2430	TC_2=3140	TC_3=4986	TC_v=8053	TSC=22208	

Note that we apportioned the reduced transportation cost under VMI based on the ratio of actual transportation cost, i.e. we assumed that the benefits of the reduction in the total transportation cost are shared on the basis of the transportation cost incurred when operating independently.

Before carrying out the numerical analysis, it is important to understand the change in GHG emission with a change in the production rate (Figure 2). The graph is so obtained due to the quadratic relationship between the two factors as expressed in equation (5), as discussed in Jaber et al. (2013).

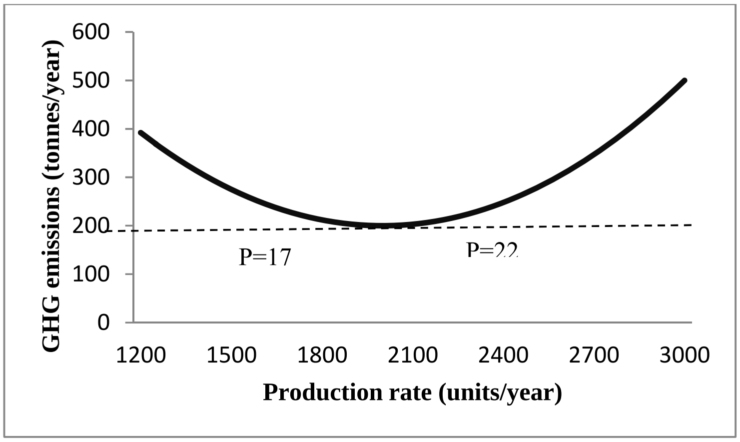

Figure 2: Change in total GHG emissions with an increase in the production rate

Next, in order to test the performance of the two models over a large variety of operating conditions, we conducted a detailed sensitivity analysis for a number of parameters as detailed below.

5.1. *Effect of change in production rate*

We determined the total system cost for the models corresponding to different values of the production rate (Figure 3). The VMI system led to consistently lower costs as compared to independent retailer ordering over the entire feasible range of the production rate. It gives an indication that for the same value of total GHG emission (as the value of P is same), adopting VMI will be beneficial for the SC. Furthermore, in our case it was observed that all the three retailers as well as the vendor experienced a reduction in cost under VMI as compared to the case of retailer managed replenishment. The nature of the curve (decrease and then increase) can be explained by the levy of emission related penalty on exceeding the upper limit corresponding to the values of production rate as shown in Figure 2.

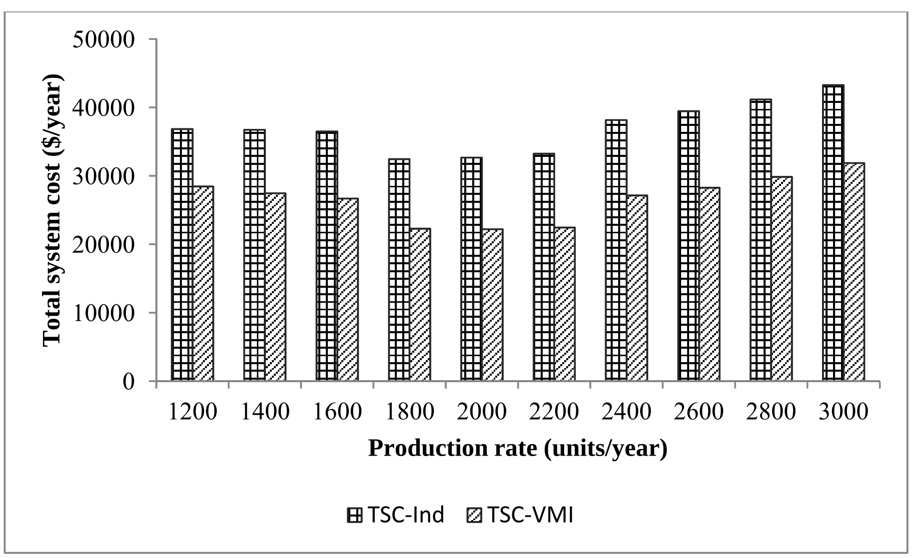

Figure 3: Change in total system cost with change in production rate

5.2. *Effect of change in the production setup cost*

The impact of a change in A_v on the total system cost and total GHG emissions is shown in Figure 3 below. As before, the VMI system showed superior results. At the same time, the total GHG emissions corresponding to the optimal values of the decision variables for the two systems were also lower in case of VMI.

Both the systems dealt with the increase in A_v in different ways. In case of the first model, the retailers remain unaffected by the change. Consequently, there replenishment decisions remained unchanged. In order to counter increase production setup cost, the vendor decreased his production rate, as it became relatively cheaper to hold more inventories. Under VMI the vendor had complete control of the production schedule and first tried to reduce the impact by increasing the length of the replenishment cycle. As the associated holding costs started to increase, the vendor then increased the number of sub-batches.

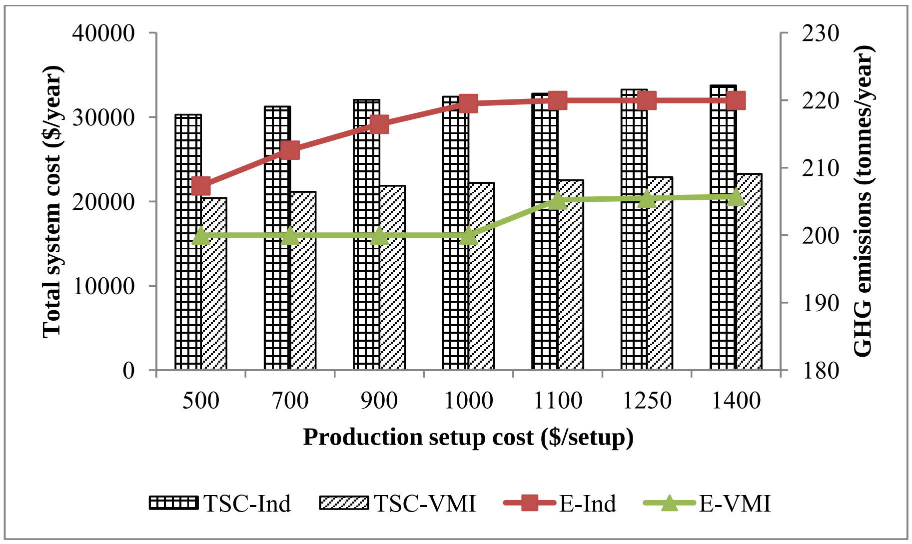

Figure 4: Change in total GHG emission and system cost with change in setup cost

5.3. *Effect of change in vendor holding cost*

We changed only the physical component of h_v, leaving the financial component unchanged. As before, the orders from the retailers remained unchanged due to change in this vendor parameter. The vendor, however, decreased the size of the production batch. Nevertheless, the vendor had no option but to experience a significant increase in cost. Under VMI, the vendor started to ship the product more frequently to the retailers, as transportation costs became relatively lower. Due to this change in the replenishment policy, the cost incurred by the retailers also changed. Some retailers experienced a reduction in cost while for others it resulted in increased costs (depending on their respective physical component of holding cost and transportation cost trade-off).
The impact of this change on the total system cost and GHG emission is shown in Figure 5. VMI system showed better results throughout the range of values of h_v. Moreover, the

percentage increase in total cost across this range was around 40% for the case of independent ordering, while it was only 11% in case of VMI. In case of total GHG emission also, the VMI system showed better results and the increase observed was also lower in its case.

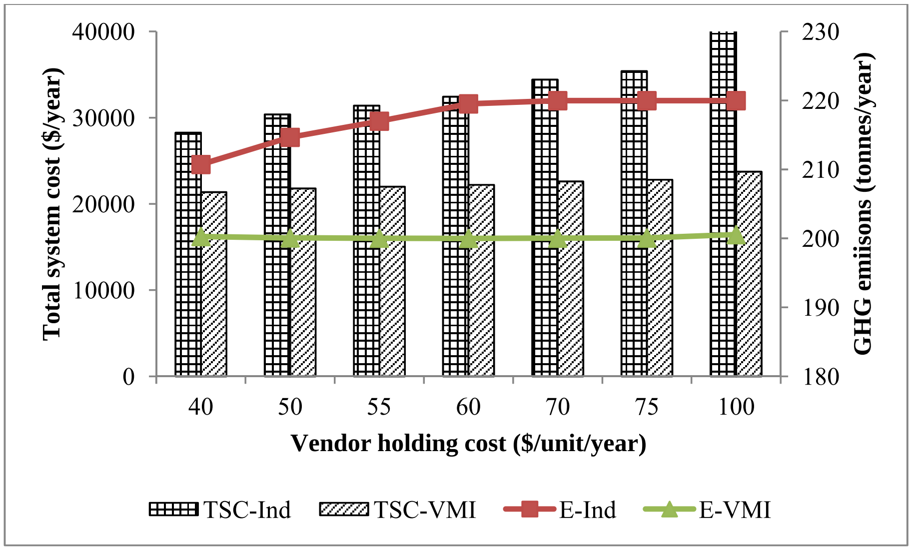

Figure 5: Change in total GHG emission and system cost with change in vendor holding cost

5.4. *Effect of change in emission tax*

The effect on change in C_t on the total system cost and GHG emission is shown in Figure 6.The total system cost increased with an increase in the tax and the cost differential between the two models was replicated in this instance also.

Interestingly, lower values of C_t resulted in similar GHG emissions under the two models, as both operated at the same production rate. This was again observed at very high values of C_t. At lower values, the relative importance of emission related cost was quite low, and hence under both models other costs had more influence on the decision variables. VMI system, on account of its more integrated operation, was better able to coordinate the production and replenishment activities resulting in more than 30% lesser costs than the independent approach. In general, the total system costs other than those related to emissions increased with an increase in the production rate, while the behavior of the latter can be gauged from Figure 2.Thus, at lower levels of the emission tax it made more sense for both the systems to operate at lower production rates (and VMI system started mimicking the approach of the independent system). On the other hand, at higher tax levels, the independent system started mimicking the behavior of VMI system in terms of continuing production at increased rates as other costs became relatively less important in comparison to the emission costs.

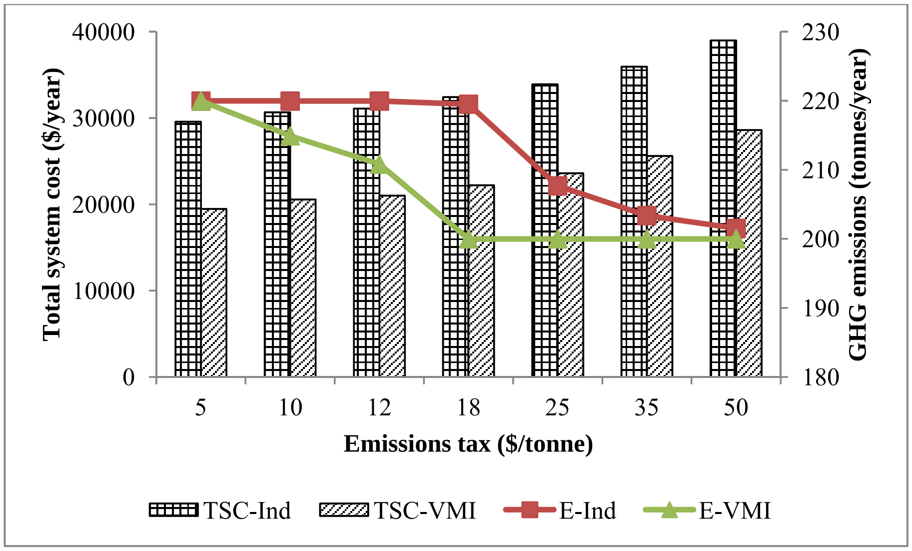

Figure 6: Change in total GHG emission and system cost with change in emission tax

5.5. *Other parameters*

We also studied the impact of the change in the upper limit of the production rate. As expected, at values more than that corresponding to the respective optimal rates obtained, the behavior of the two models remained unchanged. However, between P=1745 (optimal for the case of retailer managed replenishment) and P=1997 (optimal under VMI), the VMI system was able to provide a reduction in GHG emissions. This was primarily on account of being able to exploit the possibility of higher production rates due to integrated replenishment planning.

In addition, we also analyzed the impact of change in the upper limit on GHG emissions. The values of the decision variables remained unchanged. Only the total system cost increased in case the penalty had to be levied. However, when in addition to a reduction in the limit of emission the associated penalty cost was also increased, the vendor switched to higher production rates. This increase allowed him to avoid the penalty, and at the same time his cost increase was not found to be relatively small.

6. Discussion

The analysis in the previous section provides several interesting insights for both executives in business organizations as well as policy makers in the government bodies. From the perspective of the organizations involved, it makes sense to evaluate all avenues of properly aligning the business processes. In our case, VMI offers the opportunity to avoid settling for local level optimization. Instead, by focusing on the elongated chain the total system can benefit. However, it must be pointed out that not all the retailers may be better off under all circumstances. Thus, parties must be vigilant in protecting their respective interests, and at the same time they must be flexible enough to adjust their operations by taking a holistic view. It is here that the perspective provided by Hines et al. (2000) becomes important. They characterize VMI as a process with potential benefits for the members involved in which the parties share a common understanding of the expectations and payoffs within an overall mutually agreed framework. One approach for apportioning the benefits generated could involve the non-hierarchical negotiation-based scheme suggested by Dudek and Stadtler (2005).

In summary then, our analysis suggests that perhaps the only requirement for exploiting the overall potential of the SC is the willingness to expand the scope of thinking in terms of the modes of operation possible. This brings us to the role of policy makers in this entire process. The ability to levy taxes and penalties is indeed a very potent tool in the hand of the decision makers that has a profound impact on business planning. If yielded effectively it can serve to benefit the larger society. For example, driven by higher carbon taxes organizations may start to rethink and redesign their operations so as to establish more effective means of collaboration across the value chain. This impetus may also help the organization to discover hitherto unexplored facets of process improvement. At the same time, the policy makers need to be aware of the practical considerations of business. Lack of appreciation in this regard may result in unwanted damage to the business. For example, as shown in our analysis too low a value of the limit on emission coupled with a high penalty did nothing to incentivize the organizations to change their way of functioning. It simply placed unviable constraints. Under this scenario, those who could pay the penalty would do so (leading to economic losses which would have to be recovered from the customers), while the others would simply cease working (which is again a loss for the society, and contrary to the goals of such environmental policies). Thus, the policy makers must be careful in arriving at the parameters governing the application of such policies and should be able to balance the need for current benefits without compromising on the future potential and interests of all the stakeholder are take care of. This, after all, is what sustainable development is all about (Brundtland Commission, 1987).

7. Conclusion

In this paper we considered an integrated approach to managing the production, inventory, transportation and emission planning problem. Our model incorporated the environmental policy parameters like emission tax and emission upper limit to arrive at optimized mode of operation. We show that using VMI enabled SC coordination businesses can reap economic rewards, and at the same time they can reduce their GHG emissions. Sensitivity analysis carried out in this paper provided many useful insights to business managers in terms of providing impetus to aligning business processes across organizations, as well as to public policy planners in terms of designing the incentive structures that are grounded in reality.

Our work builds on recent realization among the academic and practitioner communities that operational policies and business practices present an untapped avenue of exploration with a focus on environmental sustainability without sacrificing economic profits.

This paper can be extended along multiple dimensions. Analysis of such systems with more complex value chains may provide more practical insights. Competition between the retailers and its effect on the coordination among the members can be another fruitful area of research. Mechanisms for redistributing the benefits generated may also be explored.

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